The CERN Linear Collider

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Abstract

The CERN study of an electron-positron linear collider is concerned with a two-beam system powered via a superconducting drive linac. The study pursues the development of suitable technologies for a 2 TeV (centre-of-mass) collider in the longer term but concentrates, now, on a 500 GeV first stage for which the two-beam system developed by us appears very suitable. Results are reported on the 30 GHz main linac, the drive beam and the final focus system.

INTRODUCTION

Without abandoning the long-term goal of a 2 x 1 TeV machine, the study of a CERN Linear Collider - CLIC - now follows specific physics interests in concentrating on a 2 x 250 GeV version for which the system under development appears to be a very serious contender. It is considered of paramount importance, however, that such a relatively low-energy project should be readily extendible into the TeV range. Much emphasis is put, therefore, on developing a technology which permits a reasonably high accelerating gradient.

The tentative design aims at 80 MeV/m. Since the main linacs for such a gradient have to be normal-conducting, an unusually high frequency - 30 GHz in fact - has to be chosen if the high gradient and a high macroscopic repetition rate are to be reconciled with tolerable power dissipation. Both choices of basic parameters - 80 MeV/m and 30 GHz - have been confirmed by a systematic parameter optimisation study [1]. With this gradient, the length of a 2 TeV (centre of mass) collider is about equal to the LEP circumference of roughly 30 km; an 0.5 TeV version is closer to a LEP diameter - where it would actually find a good site from all points of view.

The proposed solution is a two-beam scheme in which an intense *drive beam* of a few GeV average energy, accelerated by continuous-wave superconducting cavities, travels parallel to the main beam along the entire length of the accelerator. Pulsed microwave power is extracted from the bunched drive beam and fed into the main linac by means of *transfer structures* and short waveguide feeders. Two kinds of problems have to be faced, therefore, namely those presented by tolerance requirements and wake fields of a high main-linac frequency and those connected with the drive beam.

In an 0.5 TeV collider the drive beam, once preaccelerated to 3 GeV in the injector complex, requires no reacceleration. In a 2 TeV machine, reacceleration by superconducting cavities *is* required but can be concentrated in three local stations at about 4 km spacing. In either case, therefore, the main accelerator tunnel requires access pits at 4 km distance only and is kept free of any equipment connected with high power transfer, high voltage, cryogenics or limited operational life, a feature which turned out very important in LEP experience. A crossection of the CLIC tunnel is shown in Fig. 1.

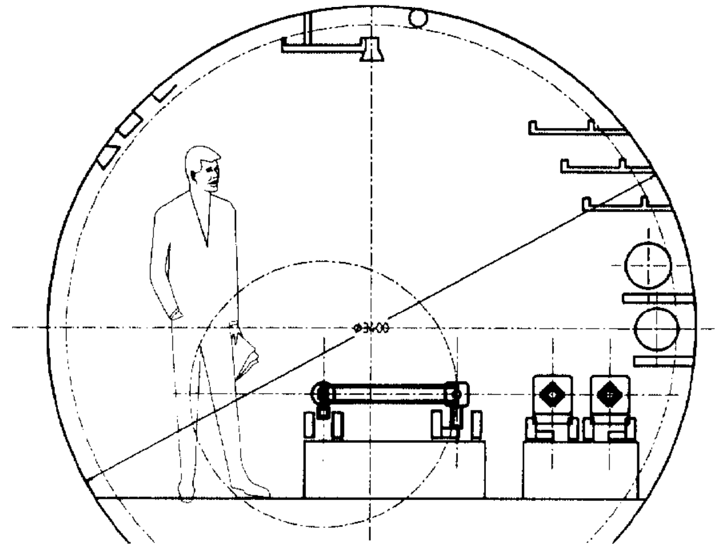

Fig. 1 Crossection of the CLIC tunnel. Shown from left to right is the drive beam (transfer structures and focusing) the main beam (high-gradient structures, microalignment and focusing) and beam transport for both beams at injection energy (3 and 9 GeV respectively) from a central injector complex to the linac input. The large circle is the outline of the superconducting drive linac which is *not* situated in the main tunnel but determines the distance between main and drive beams if the machine is to be readily extendible beyond 2 x 250 GeV.

THE MAIN LINEAR ACCELERATORS

Special technologies have been developed for cost effective fabrication of the main accelerating structure meeting the requirements (tolerances and surface finish) of a microwave frequency ten times above present-day practice. As a result, two full-length 30 GHz structures have been built and tested [2].

An iris-loaded section contains 84 cells and has a coupler (to WR 28 waveguide) at each end. The aperture diameter is 4 mm, the cell diameter 8.7 mm and the group velocity 8.2% c. The outer diameter of the structure (35 mm), machined to ±1 μm precision and concentricity with the beam aperture, serves as the reference for alignment. The cells are pumped through four radial holes via brazed-on manifolds. Parallel channels for water cooling are drilled into the copper. Each cell can be deformation-tuned by forming a pair of diametrically opposite dimples, but the precision attainable in diamond machining and vacuum brazing is such as to make us consider elimination of any tuning. So far, our accelerating structures are constant-impedance structures. Our attempts to accommodate a modest amount of multibunching by stagger tuning are described elsewhere at this conference [3, 4]. BNS-damping within a bunch will be provided with the help of microwave quadrupoles [5] formed by giving some accelerating structures flat-shaped cells but normal, circular apertures. About 5% of the accelerator will be of this kind.

About 2×10^4 accelerating sections containing 2×10^6 discs will be required for an 0.5 TeV collider. In considering mass fabrication it becomes apparent that the fabrication cost will be dominated by the seemingly trivial operations of disc-forming, roughing, drilling, cleaning, inspection and handling. Therefore, an industrial study of suitable fabrication processes has been launched with a view to obtaining a first-order cost estimate.

It might be suspected that a potential problem at the high acceleration gradient of CLIC could be the accumulation of *dark current* formed by field-emitted electrons which are trapped in the accelerating field. However, the threshold gradient scales linearly with frequency and computer simulations [6, 7] show it to be well above 100 MeV/m at 30 GHz. It is, nevertheless, reassuring that a structure made by the CERN technology but scaled down to 11.4 GHz and tested at KEK Japan in the frame of a collaboration, readily exceeded 100 MeV/m gradient, the limit being set by available power.

The strong transverse wakefields associated with the high accelerating frequency and the strong BNS damping required for stability lead to tolerances of only a few micrometer of rms jitter for structures, quadrupoles and beam position monitors [1, 8]. This, therefore, has led to two hardware developments.

One the one hand, the beam position with respect to the accelerating structures (not the quadrupoles) will be measured to sub-micron resolution by means of E_{110} cylindrical cavities, fabricated integrally with the accelerating structures [9].

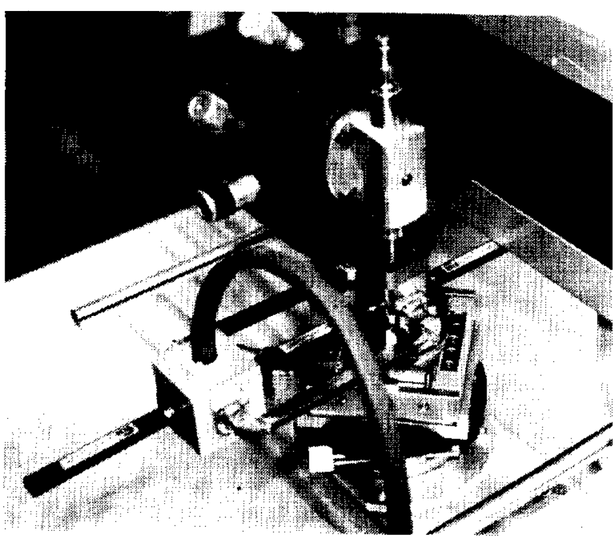

Fig. 2 Microwave set up for testing sub-micron beam position monitor. Above: probe holder and micro-mover. Below: the diamond-machined E_{110} cell, two diametrically opposite output waveguides, a magic-tee and a flexible waveguide for the differential output.

Fig. 2 shows a setup in which a small antenna like probe is moved across the aperture of a prototype monitor with the help of mechanical micro-movers. The result, shown in Fig. 3, clearly demonstrates a resolution better than 0.1 μm.

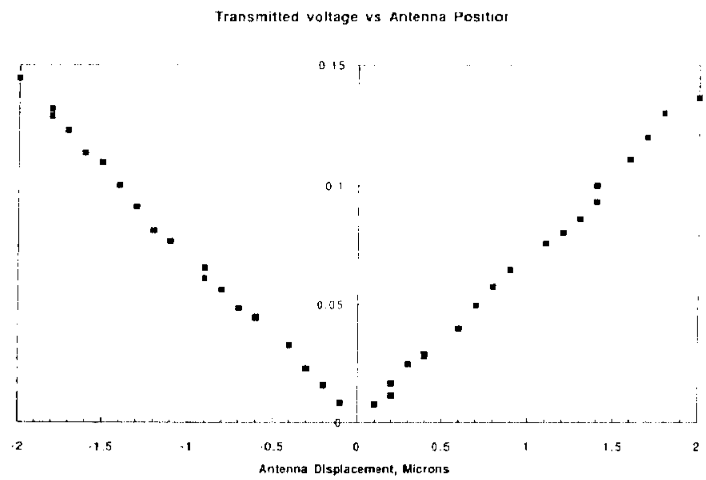

Fig. 3 Output of beam position monitor for ± 2 μm travel of a beam-simulating electrode.

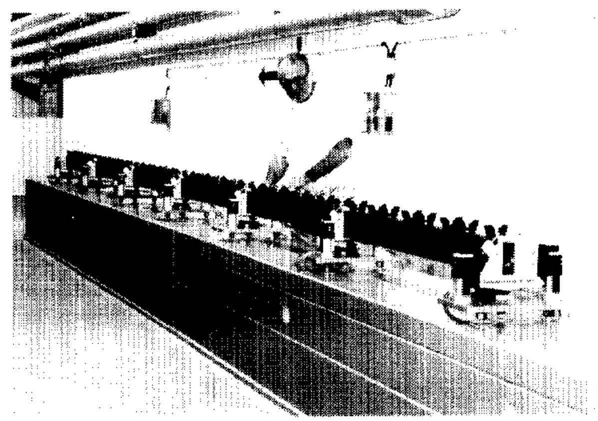

Fig. 4 Six-unit prototype of submicron self-aligning support structure.

On the other hand, sub-micron automatic alignment in an underground test facility has already been demonstrated and reported two years ago [10]. Together with the results with the beam position monitor reported above these tests form a demonstration in principle that the micrometer tolerances required for a 30 GHz system can indeed be met. A ten meter complete prototype of self-aligning structure is nearing completion. It is shown in Fig. 4.

THE DRIVE BEAM

The multibunch high-intensity drive beam runs parallel to the main beam at about 1 m distance. The drive beam delivers energy to 30 GHz travelling-wave transfer structures which thus form the pulsed RF power sources of the main linac sections to which they are connected by rectangular waveguides. The drive beam is accelerated by superconducting cavities.

A multi-frequency scheme has been worked out for this superconducting drive linac [11]. Firstly, the beat between closely spaced fundamental frequencies will compensate the transient beam loading. Secondly, the addition of beam-driven cavities at two harmonics will linearize the waveform over half a wavelength, so as to permit an extension of the drive-beam train - with concomitant reduction of charge - by up to a factor of four compared with single-frequency operation. Further charge reduction by the addition of RF pulse compression at the transfer structure output is under development.

Since the drive bunches suffer different and strong decelerations in the absence of longitudinal focusing, it is clear that the drive beam will accumulate a large energy spread along its path, as well as a large increase of transverse emittance.Tracking the beam energy spread and the associated chromatic growth of transverse emittance through a suitable FODO focusing system confirmed [12] that the beam survives the full (active) length of 12.5 km of a 1 TeV main linac, albeit with over 20% energy spread and filling the available aperture at the end. Preacceleration to about 6 GeV and three reacceleration stations, located at discrete access points to the machine, are foreseen for this case of a 2 TeV collider. No reacceleration is required in a 0.5 TeV machine where each of the two drive beams - after being preaccelerated to 3 GeV in the injector complex - travels the entire linac length of about 4 km (3.2 km active) without further acceleration.

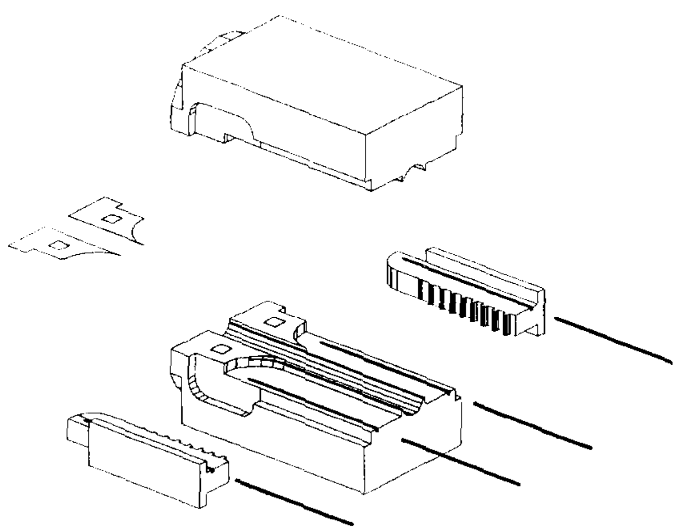

Fig. 5 One end of a 30 GHz transfer structure made of two halves. Total length: 60 cm. Central bore: 12 mm. The black lines (lower right) and the thin foils (middle left) indicate the placing of the brazing alloy (Curtesy KM kabelmetal)

The transfer structures for pulsed power generation take the form of smooth beam tubes of 12 mm diameter with two periodically loaded power-collecting waveguides running in parallel and coupled to the tube by continuous slots. The particle beam is in synchronous interaction with a forward $2\pi/3$ mode. Transverse wake fields, excited by an off-centre drive beam, are nearly synchronous with the bunches but have a 90° phase offset, affecting mostly the head and the tail (and in opposite signs). Tracking results indicate that this effect remains tolerable. So far, the transfer structure has been developed with the help of 9 GHz scale models as well as by computation. A 30 GHz prototype is being constructed by industry (Fig. 5). Details of the transfer structure development are given in three compagnon contributions [12, 13, 14] to this conference.

The generation of the required drive beam is a difficult problem for which several solutions have been proposed. One of these employs a battery of laser-driven photocathodes in high-gradient r.f. guns. This has been the subject of a test facility which has begun operation. Short bunches are obtained from a CsI cathode excited at 209 nm wavelength and exposed to 100 MV/m peak extraction field in a 3GHz gun. So far, 2.7 MW of peak 30 GHz power have been produced in one of the prototype main linac structures using this beam.

A promising scheme under active study employs a single-pass free electron laser for bunching. Only one preinjector is required which directly generates the complete configuration of drive bunches. An experimental test carried out in collaboration with a specialised laboratory is in preparation. This is described in another contribution to this conference [15]. Other proposals make use of bunch compression at different stages of preaccelaration [16, 17].

THE FINAL FOCUS

Chromaticity-corrected final focus systems for 2 TeV and 0.5 TeV have been developed [18]. In the latter case the critical-photon-to-particle energy ratio is 0.15 and the beamstrahlung energy spread is 5.9%. Work is in progress concerning the effect of the crossing angle (including crab crossing), collimation and masking and compensation of the solenoid field of the detector by an antisolenoid

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